Project Report: Ecosystem to Biosphere Modeling

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Project Progress

We refined the model of hypersaline mats Microbial BioGeoChemistry (MBGC). Working towards publication of the first version of the model (submitted May), we adopted many improvements into the model, or researched them as future adaptations. One assumption that was questioned was that oxygen supersaturation inhibits oxygenic photosynthesis. Whereas this simplifying assumption was effective in earlier models, the midday reduction in photosynthesis that occurs in the mats is more likely due to photorespiration. This has consequences for the carbon cycle and we have researched the inclusion of photorespiration into the model.

We ran sensitivity tests to answer outstanding questions about the relative diel changes in the rates of sulfate respiration and dissimilatory sulfate reduction (dsr); (Table 1; Figure 1). The relative frequency of these processes has consequences to differential interference contrast (DIC) emissions (Figure 1). We found that cyanobacterial fermentation is critical in supplying H_2 for dsr and that nighttime sulfur oxidation in colorless sulfur bacteria is critical in supplying S^o for cyanobacterial fermentation.

Table 1

DIC Sinks:		
[1,2]oxygenic photosynthesis (CYA)	1:1 CO_2 fixed: O_2 released	$CO_2+H_2O \rightarrow (CH_2O)+O_2$
[2]anoxygenic photosynthesis (CYA)	1:1 CO_2 fixed:H_2S oxidized	$2CO_2+2H_2S+2H_2O \rightarrow 2(CH_2O)+H_2S_2O_3$
[2]anoxygenic photosynthesis (PSB)	2:1 CO_2 fixed:H_2S oxidized	$2CO_2+H_2S+2H_2O \rightarrow 2(CH_2O)+H_2SO4$
[2]chemosynthesis (PSB)	1:2 CO_2 fixed:H_2S oxidized	$2CO_2+4H_2S+6O_2+2H_2O \rightarrow 2(CH_2O)+4H_2SO_4$
[2]chemosynthesis (CSB)	1:2 CO_2 fixed:H_2S oxidized	$2CO_2+4H_2S+6O_2+2H_2O \rightarrow 2(CH_2O)+4H_2SO_4$
DIC Sources::		
Diffusion from water		
Aerobic respiration (CYA)	1:1 CO_2 :O_2 used	
[2]Sulfate Reduction (SRB)		
fermentation + dissimilatory SR	*1.15:1 CO_2:H_2S released	$4C_6H_{12}O_6+4H_2O+4S^{2+}+3H_2SO_4 \rightarrow 8CH_3COOH+8CO_2+7H_2S$
sulfate respiration	2:1 CO_2 :H_2S released	$2(CH_2O)_6+H_2SO_4 \rightarrow 2CH_3COOH+2CO_2+H_2S+2H_2O$ $2(CH_2O)_6+3H_2SO_4 \rightarrow 6CO_2+3H_2S+6H_2O$

[1] from Canfield and Des Marais 1993; [2] from van Gemerden 1993 - see text; * these two ratios are combined in the model - see text

Table 1. Stoichiometric ratios that affect the DIC budget in MBGC and their associated equations. The bacteria associated with these processes are: Cyanobateria (CYA), purple sulfur bacteria (PSB), colorless sulfur bacteria (CSB), and sulfate–reducing bacteria (SRB).

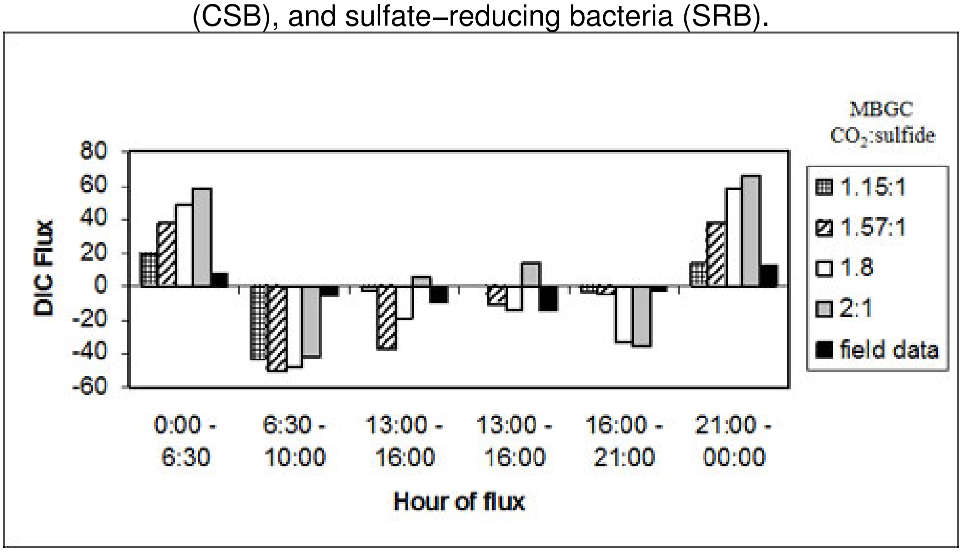

Figure 1. DIC flux across the mat boundary in mM m−2 hr −1. The figure compares field data averaged each time period) with MBGC results with various levels of sulfide created per CO2 released.

These findings have consequences for further development of the carbon cycle that will include organic carbon and methanogenesis. We have begun the development of these new carbon components by gathering literature on photorespiration, cyanobacterial fermentation, and methanogenesis in microbial mats. We focused on several sources of carbon, specifically exudation during oxygen supersaturation leading to photorespiration, fermentation, and decomposition. This can be described as a ‘top−down' approach because it examines sources of organic C. We are concurrently taking a ‘bottom−up' approach looking at one critical sink of organic C:

methanogens. In hypersaline, sulfate–rich environments, these microbes use methylamines because they are noncompetitive substrates. The precursors of methylamines are osmoregulants released during the decomposition of hypersaline bacteria, such as glycine betaine. The current challenge is to find or model pool sizes of these critical osmoregulants.

Highlights

- We submitted a paper describing the first version of Microbial BioGeoChemistry.
- We gave two presentations at national meetings.
- We conducted sensitivity tests that identified critical areas of model innovation to the carbon cycle.
- We researched critical portions of the carbon cycle including organic carbon release from cyanobacteria and decomposition, and also including methanogen activity.

Roadmap Objectives

- ***Objective No. 4.1:*** Earth's early biosphere
- ***Objective No. 5.3:*** Biochemical adaptation to extreme environments
- ***Objective No. 6.1:*** Environmental changes and the cycling of elements by the biota, communities, and ecosystems
- ***Objective No. 7.2:*** Biosignatures to be sought in nearby planetary systems

Mission Involvement

This investigation is designed to provide science background and interpretive capacity for Mars in situ and sample return missions, as well as for telescopic life detection (e.g., TPF). By focusing on the production of mineral biosignatures in environments analogous to possible early Martian systems, and on the production of volatile biosignatures in photosynthetic ecosystems, these studies will provide an enhanced scientific context for the eventual return of data from Mars and TPF missions.